5 Soil health scenarios

Faber, J.H., Van der Pol, J.J.C. and Thomsen, M.

Existing changes and variations in soil health prove the need for a better understanding of vulnerable soil properties and processes and in relation to chemicals, the degree of importance of soil contamination to the overall soil ecosystem health.

Soil health is not maintained by protecting people and ecosystems from side effects of human activities in terms of land use and soil management practices. The soil itself is an ecosystem and soil health in reference to sustainability and ecosystem services needs to be addressed by understanding the links between biodiversity, stability, productivity and nutrient dynamics of the soil as an ecosystem.

For a sustainable use of the soil resource, and changing land uses, what to protect is therefore soil properties in terms of ecosystem structure and functioning, biodiversity and soil processes that are needed for the soil ecosystem to remain healthy. Impacts on soil ecosystems therefore need to be quantified not only in terms of chemical stressors, but equally important by vulnerable soil properties and processes influenced not only by chemical contamination, but also by other soil influencing management practices and land use parameters.

The System Model Approach as described in Chapter 2 is used to set up an approach to analyze soil vulnerability as related to land use types. The description of soil health are based on ecosystem services, defined as the properties or services expected to be provided by the soil ecosystem to society, and in response to these expected ecosystem services a set of soil ecosystem requirements needed to be fulfilled. Once these ecosystem requirements are known, and the relative importance of the individual criteria fulfilling these ecosystem requirements with respect to the provided services, the importance of vulnerability criteria of different land uses may be evaluated. The impacts of chemical stressors on the identified vulnerability criteria may be evaluated for different types of land uses or a single land use with varying pressure from chemical stressors. The identification of high-risk scenarios for soils with respect to chemical stressors therefore needs to include two stages: firstly, the relative importance of ecosystem requirements expressed as vulnerability criteria, and, secondly, the influences by chemical stress on these vulnerability criteria.

For assessment the ecosystem can be defined either by a simple choice or based on an analysis that can identify the most vulnerable and/or highest impacted ecosystem. In terms of the System Model in Chapter 2, this means, that the ecosystem can be chosen directly to form the main problem, or to be a part of the Scenario Composition Model. This is illustrated in Figure 5.1.

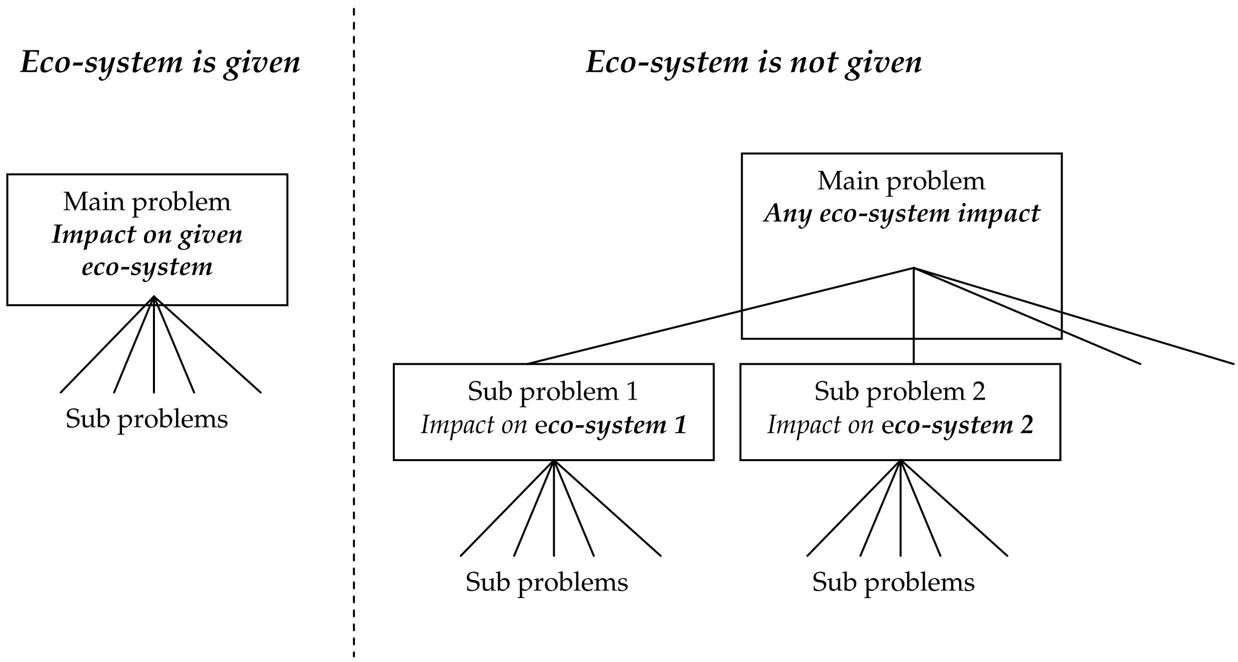

Figure 5.1. The structure relates to the structure of the problem tree as defined in Figure 2.2. If the type of land use and ecosystem is specified for a given risk assessment to be performed, then the main problem is defined by the chosen ecosystem. If the ecosystem is not given then it will become a part of the risk assessment and thus the problem tree to analyze any possible ecosystem for harmful impacts. A reversal of the risk problem towards the goal may for any type of land use be expressed as the maintenance and enhancement of soil ecosystem health. This means that the most sensitive measures of soil health and causes of impacts, where present, needs to be identified and reversed.

The hierarchical description of interrelations between the main problem and sub-problems is a systematic approach for mapping all possible aspects of given risk scenarios, increases awareness of ignorance, gaps in knowledge, science and uncertainties. Furthermore, the approach delivers qualitative and semi-quantitative information that may be regarded as supportive information behind any risk assessment and resulting risk estimates.

In this chapter, a methodology for scenario description of soil ecosystem health is developed with the starting point of an undefined type of land use and ecosystem. The System Model approach is adopted to identify ecosystem services and their breakdown into a set of indicators for soil ecosystem health in a stepwise manner. A second paragraph is focussed on development of methodology for the assessment of vulnerability in wildlife for chemical contaminants in soils and sediment. Lacking toxicological data, the method is based on autecological species data available in the literature.

5.1 Scenario description for soil ecosystem health

In this paragraph focus is on soil ecosystem health, or just soil health. Likewise, for human health there are many underlying factors besides chemical stressors that may potentially influence the health status in positive or negative directions. Before being able to analyze highest risk conditions of harmful impacts on soil ecosystems, we need to know which soil characteristics, properties and processes are governing soil ecosystem health in general.

5.1.1 Introduction

As stated in the introductory chapter, the aim of this report is to list and test methods that can help to guarantee the best possible selection and design of risk assessment scenarios. This paragraph is focussed on soil ecosystem health. As risk assessment for soils is highly complex, it is aimed for the development of a rationale that supports risk assessment by identifying a set of the most relevant scenarios with highest risk potential. While soil ecosystems are infinitely complex, the question is simply: "What to protect?" Soils need protection against chemicals and other stressors, obviously, but in order to determine the level of protection the next question would be: "Which factors determine or modulate the risk to the soil ecosystem from pollution and other stressors?" The analysis of this question subsequently helps in the identification of scenarios and criteria. Here, the derivation of scenarios will focus on the element of characteristics and vulnerability of the biological community and ecosystem functioning in soils.

5.1.1.1 Soil functioning and land use

In most EU Member States the protection of soils traditionally has been focussed on the overall protection of species and soil processes ('multifunctionality'). In the area of clean-up and remediation of contaminated land attempts have been made to derive soil remediation targets in view of land use ('suitability for use'), aiming at increased cost-efficiency. Another novelty is the development of biological references for soil quality (Rutgers et al. 2005), acknowledging that soil communities are a strong reflection of land use and that sustainable land use implies proper soil management to enhance and preserve the soil community that is thought representative for a particular type of land use. Therefore, both in the protection and in remediation of soils, the land use perspective and the concept of 'suitability for use' may play increasingly important roles in the near future. The question then becomes: "What to protect, given a particular land use?" (Van de Leemkule 2001).

A scheme for land use and soil quality has been developed (Faber 1997; Van de Leemkule 2001; Faber et al. in NoMiracle Deliverable D114), focussing on ecological suitability for use. Ecological requirements for land use were defined as conditions that need to be fulfilled in order for the soil ecosystem to provide ecological services desired by society regarding a particular use of land. If chemicals or other stressors should adversely affect ecological requirements, then ecotoxicological problems will hamper land use, and the achievement by stake holding parties of their particular goals for land use will be limited below respective targets. Soil ecosystem health is thus assessed in terms of suitability for use (much alike "good water status" is aimed for in surface water management, as induced by the EU Water Framework Directive).

This paragraph is mainly focussed on the derivation of relevant criteria for soil health. Ecosystem services are used as proxies, and subdivisions are made for ecological requirements and subsequent soil ecosystem parameters ("indicators"). Toxicological data for these indicators (if sensitive to a particular stressor) are then compiled to make up sensitivity criteria for soil health. The criteria are used for identification and selection of high-risk scenarios for the quantification of ecological risk. Each criterion represents a set of toxicity data for soil ecosystem parameters of biological, chemical or physical nature. These parameters may be used as indicators for ecosystem services, as they are directly measurable and quantifiable. Should toxicological data for identified sensitivity criteria not be available, a data gap is identified.

Next, a tentative classification is presented of soil health criteria in terms of their relevance to land use. A limited selection of land use types is presented, for illustration purposes. This classification into land uses and ecosystem services may serve as a basis to recognise vulnerable and sensitive structures and processes in ecosystems that are needed in the provision of ecosystem services. Eventually, in subsequent risk assessment soil quality standards may be developed for chemical stressors with potential impact on soil health (the main risk problem) through adverse effects on these indicators, so as to set protection levels for sustainable use of land.

In this chapter we also make use of an overview of scientific literature of toxicity data with respect to soil health criteria (Faber et al., 2006, in prep.). Criteria representing toxicological sensitivity of soil community structure and functioning are approximated by use of available toxicity data. Toxicity data with respect to soil health criteria may then be evaluated in order to assess specific vulnerabilities in ecological requirements, and toxicity data may subsequently be used to derive threshold concentrations for soil quality and risk assessment, e.g. by means of PEC/NEC evaluation.

Obviously, by approximating the criteria describing soil biological communities by single species or processes by available toxicity data, there is liability for total ignorance of important criteria in the pre-selection of high risk scenarios for subsequent ecological risk assessment (*sensu* Walker et al., 2003). This can never be prevented, but new data and progressing insights may always be incorporated.

5.1.2 Problem decomposition model

Soils in general may provide a number of ecosystem services, and depending on the intentional land use some of these may be considered more relevant than others. In the present chapter basic criteria for soil ecosystem functioning are listed. A systematic approach is used to identify highest-risk scenarios in land use on the basis of available information. Below, ecosystem services are listed and subdivided into ecological requirements and subsequent indicators. Indicators influenced by chemical stressors are of relevance for the identification of specific toxicological sensitivity criteria, used as input data in the criteria model used for the selection of worst-case scenarios in subsequent risk assessment. The Problem Decomposition Model for the maintenance and enhancement of soil health may for every type of land use be illustrated as in Figure 5.2, following the stepwise approach of a problem tree (*cf.* paragraph 2.2).

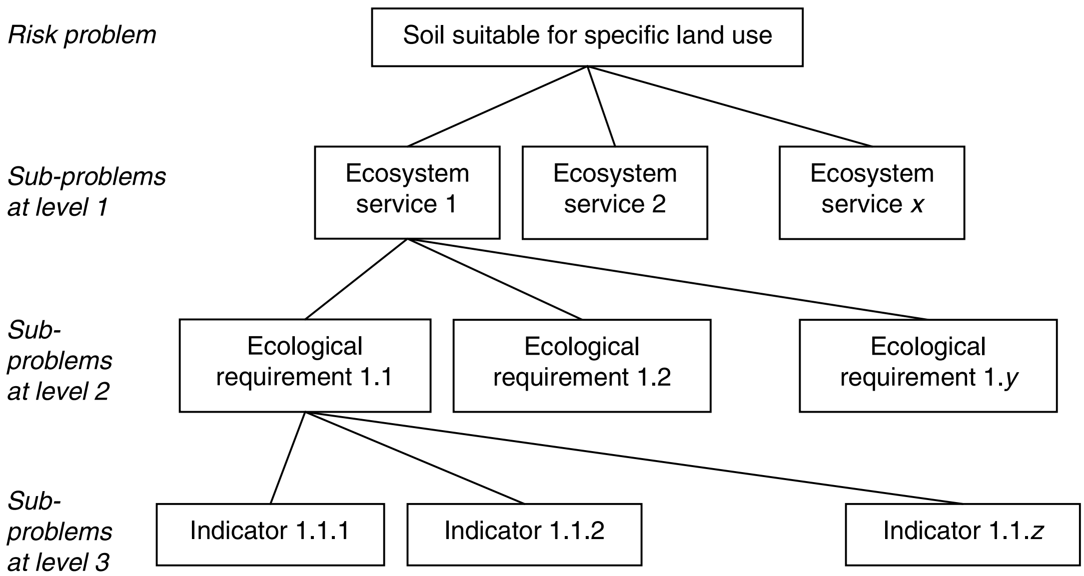

Figure 5.2. Problem tree configuration for soil health, depicting land use requirements in terms of soil ecosystem services with subdivisions through ecological requirements down into indicators for essential soil ecosystem structures and processes.

5.1.2.1 Risk problem: Suitability for land use

Risk assessment of contaminated land may be focussed on the suitability for use. Scenario analysis for the purpose of pre-selecting high risk scenarios for risk assessment can be attuned for different types of land use. Any type of land use may be specified. The analysis may focus on a course level of land use classification, *e.g.* agriculture, nature, recreation, inhabitation, industry, etc., or focus on finer levels such as dairy farming, poultry farming, farmland, or forestry, as refinements of agricultural land use. Obviously, any scenario analysis and risk quantification will gain in accuracy by precise definitions of land use and goals for use. The enumeration of ecosystem services to support land use should, however, be independent and consistent. In other words, we believe that ecosystem services should not be specified and differentiated according to the type of land use, but that any soil should (potentially) be providing these services. Rather, depending on the type of land use particular ecosystem services should be enhanced or stimulated by proper and sustainable management and usage of soil. The listing of ecosystem services in the following is therefore valid for any type of land use, but the relevancy of particular services may strongly vary with type of use. *Mutatis mutandis* the rationale of listing should also be valid for the aquatic environment.

Sub-problems at level 1: Ecosystem services

Soil ecosystem health can be determined from soil physical, chemical and biological properties as, for example, activity levels, stability, resilience and organisation. These properties cannot yet be expressed in well-defined representative measurable sub-problems for the ecosystem as a whole. Because of the complexity of the soil ecosystem indicators as such might not be available at all. Therefore, new ways of looking at the soil ecosystem health have to be found. Ecosystem services can be used as proxies for ecosystem health (TCB 2003; Breure 2004).

The following set of soil ecosystem services were recognised as relevant for all open types of land use (TCB 2003):

(A) Soil fertility,
the capacity to provide nutrients and biomass;

(B) Adaptability and resilience,
the capacity to adapt, or the fragility upon disturbance and land use changes;

(C) Buffer and reaction function,
storage and buffering of water, gasses, chemicals, energy, cation exchange capacity, breakdown and synthesis of chemicals (detoxification, humification)

(D) Disease suppression and pest resistance,
the natural capacity to prevent and suppress pests and diseases

(E) Biodiversity[3],
genetic, functional and structural;

(F) Physical support;
supportive capacity, historical archive, landscape identity.

Sub-problems at level 2: Ecological requirements

For the above listed ecosystem services, ecological requirements were defined (cf. Appendices A-F respectively). Ecological requirements are the actual structures or processes of the ecosystem that underlie ecosystem services; they require some minimum level (qualitative or quantitative) in order for the ecosystem to function properly. In other words, for soils to deliver any desired ecosystem service to society, the ecosystem needs certain aspects to be fulfilled. Ecological requirements can be assessed using proper indicators for measurement.

Sub-problems at level 3: Indicators

Indicators were denominated as potential means to assess the state of ecological requirements; they may include indicators for soil biota, soil processes, or conditions of ecological nature. Numerous indicators may be conceived; preference was given to those that have been used in toxicity testing in the field or in the laboratory. If no toxicity threshold data are available in the literature, the number of indicators for sub-

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[3] Biodiversity is acknowledged here as an ecosystem service from a policy viewpoint: the diversity of life in the soil is considered to be the driver for soil functioning. As such, soil biodiversity may even be appreciated as the key factor governing all soil ecosystem services. Given this importance, biodiversity was listed explicitly to enforce biodiversity policy through linkage with environmental policy in a wider sense (TCB 2003). From a scientific viewpoint, biodiversity is rather a complex of factors maintaining and regulating ecological requirements for soil functioning, and it may not be considered an ecosystem service as such (Rutgers et al. 2005; this study).

problem 2 was limited to one; otherwise, as many indicators were incorporated as were available in conjunction with toxicity data (cf. Appendices 5A to 5F). Toxicity data were compiled from literature to make up datasets (i.e. approximations of toxicological sensitivity criteria) that may be used for ranking risk scenarios in the Scenario Selection Model (paragraph 2.2.4), as well as in consecutive risk assessment for soil quality targets.

Indicators for ecological requirements were assessed for susceptibility for chemical pressure (yes/no) and, if affirmative, toxicity data were searched for in the literature and Internet databases. Toxicity data were screened for cadmium, as a well studied chemical stressor, and for compounds in the NoMiracle set of test substances: chlorpyrifos, diazinon, diclophenac, lindane, methoxychlor and nickel.

Comments on the Problem Decomposition

While figure 5.1.2 suggests the possibility for a straightforward division of land use requirements in terms of soil ecosystem services down into a complementary set of indicators for ecological requirements, in practice an exhaustive identification of risk problems for soils at lower generality levels is impossible. For maximum soundness in scenario analysis it is required that subdivisions in the derivation of criteria are enumerated by a fully systematic approach following the Problem Decomposition Model (paragraph 2.2.1.) to facilitate the assessment of uncertainty from incomplete data. However, this is a complex and therefore hard – if not impossible – procedure, as subdivision levels from the ecosystem service downwards may be derived along multiple lines of scientific disciplines (ecology, taxonomy, geochemistry, physics, etc.). Also, subdivisions may be enumerated at different levels of biological integration, from the molecular scale up to the landscape and catchment scales. Scenarios may be derived from a mass balance approach, familiarity or alienity of chemicals to biological systems, or follow a process versus structure division and make distinction for functional versus structural biodiversity. Indicators may be derived on taxonomical scenarios, or define functional groups on the basis of body size, food choice, life history, or microhabitat, or combinations. And last but not least, soil communities harbour countless numbers of species that may serve as indicators for particular ecosystem services. Indicators that are derived in the end will have varying relevance as a *pars pro toto* for the entire ecosystem. As Frank Egler observed, "Ecosystems are not only more complex than we think, they are more complex than we *can* think." (Egler, 1977).

Notwithstanding this drawback and out of need for general and all-inclusive risk analysis scenarios it was pragmatically undertaken to optimize the scenario identification for ecological vulnerability of soil ecosystems to the best of our knowledge. When breaking down the risk problem for land use into ecosystem services and further sub-problems, we have aimed to apply complementary keys to identify sub-problems, but have refrained from strict completeness in enumerating sub-problems at the second level and further down. Rather, at levels of lower generality we have selected ecological requirements and indicators as the most important ('prerequisitive') set of sub-problems on the basis of expert judgement. Sub-problems that were considered non-requirements were not included. In fact, by thus selecting, the Scenario Composition Model (paragraph 2.2.2.) was applied, but without ranking yet.

The Problem Decomposition Model as illustrated in Figure 5.2 is simpler than reality. Yet, it may be attempted to subdivide ecosystem services (sub-problem 1) in fundamental components such that the division covers all relevant properties of the ecosystem. For instance, soil fertility is subdivided into biological, chemical, and physical requirements. In Appendix 5 these are denoted "Soil Fertility ecosystem service refinement indicators". The logic is that there should be no other environmental factor potentially affecting soil fertility that is not covered by one of these three aspects. The biological aspects may be further refined into decomposition, production, and nutrient storage, representing build-up, breakdown and the standing pool of nutrients in organic and mineral forms. These aspects of the ecosystem may be considered ecological requirements (sub-problem 2), as they require to be maintained at minimum levels to sustain ecosystem services. In turn, further refinement indicators divide the ecological requirements. Decomposition for example links down with functional and structural biodiversity[4], and so forth.

The full description of problem decomposition models for the defined ecosystem services A to F is given in tabular form, in respective separate Appendices 5A to 5F.

5.1.3 Scenario Composition Model

Focussing on the risk of impact from chemicals and other stressors, soil health vulnerability criteria that may potentially be influenced by such stressors need to be identified. The sets of indicators representing sub-problems related to ecosystem services for land use were assessed for susceptibility for chemical pressure (yes/no) and, if affirmative, were assigned "Y", indicating that these indicators are to be included in the scenario composition model. Indicators susceptible to chemical stress are marked in the second last column of the Tables given in Appendices 5A to 5F (with the title "susceptibility towards chemical stressors").
The indicators may likewise be assessed in terms of susceptibility for other stressors, but this was not done in our study.

Discussion of indicator list
Soil fertility is an important and complex ecosystem service; a large set of indicators was enumerated, clearly outnumbering any listing for other ecosystem services. This is perhaps a result of bias from available knowledge or personal experience. However, too many indicators are not a problem, but too few might be, as it can result in ignorance from data gaps. Would these be critical data gaps? How can we know this? Perhaps soil biology has focused upon the most important aspects in past decades to overview at least the very largest part of important soil health criteria. But again, how can we know this? On the other hand: it is hard or perhaps impossible to identify missing criteria. We have disclosed only a handful:

- actinomycetes;
- autotrophic bacteria;
- pollinating insect families with soil dwelling larvae (such as some hoverflies and beetles);
- lichens, and other symbionts;
- faunistic and floristic genetic diversity; …

Some of these are thought to have minor contributions to ecosystem services (which is probably a reason for not being studied by ecotoxicologists).

There is misrepresentation of plant ecological indicators, except perhaps for primary production under soil fertility. Although this is a clear omission[5], this may not jeopardize risk assessment scenarios much, as plants are not considered to be most sensitive to the chemicals assessed here (see section 5.1.4).

Some ecosystem services may have considerable overlap between them, causing the same ecological requirements and indicators to appear more than once. This is for instance the case for ecological requirement 'soil organic matter maintenance', which appears both for biological aspects as for physical aspects of the ecosystem services, 'soil fertility' and 'soil buffering capacity'. In this case, one must reconsider if the fundamental structuring of the problem tree should be adjusted or if this is simply an expression of the importance of a sub-problem for maintenance and enhancement of soil health regardless the type of ecosystem service and/or land use. In fact, the reoccurrence of the same sub-problems at level 3 may be used

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[4] Functional biodiversity includes organisms of direct importance, as well as interactions between species and trophic levels, affecting the performance of the soil ecosystem with respect to a particular ecosystem service. Structural biodiversity includes numbers, biomass, the population structure of species (including genetic diversity), and the species composition of communities.

[5] We have limited the project-time investment here for efficiency reasons.

as an expression of the relevance of indicators in term of the number of ecosystem services they are related to. If indicators are susceptible to chemical stressors, the relevance may be translated into relative importance of criteria used to quantify toxicological sensitivity e.g. regardless of ecosystem service or even regardless of types of land use. There might be a set of unique soil health indicators representing minimum requirements needed to be fulfilled regardless of the type of land use. Another approach is to screen for indicators of highest toxicological sensitivity within a specific land use type.

The main purpose of working with the Problem Tree is to obtain a systematic description of the risk scenarios, sub-problems, known and unknown knowledge, data gaps by purpose of being able to describe the restrictions and conditions for a given final quantitative risk estimate. The outcome of the risk scenario description is, to the best of knowledge, the most important aspects, i.e. sub-problems, to be addressed within a risk assessment. In addition, high-risk scenarios may be identified in respect to susceptibility towards chemical stressors and read-across methodologies may be applied in case of insufficient data.

As long as toxicity data were available, multiple indicators were enumerated along single scenario subdivision lines. The multiple data illustrate the range in toxicity thresholds. The Criteria Model is able to assign the individual toxicological sensitivity criteria (which are approximators for sensitive indicators) according to relative importance for the risk problem. In this case the most sensitive indicator would be assigned highest rank prior to scenario ranking. Thus, the scenario pre-selection for risk assessment will consist of the most sensitive indicator and the highest risk candidates regarding toxicological sensitivity, i.e. a worst case approach. The range in sensitivities may be interpreted in terms of specific resiliency of the soil ecosystem.

We certainly consider that the present list may be subject to further development (by additions mostly), but we also believe that the present list will serve sufficiently well for identification of sensitive ecological requirements and ecosystem services. Further, if these indicators are evaluated by their relevance to particular types of land use, their respective toxicity thresholds may be used in the development of risk assessment scenarios for land use. This assessment may focus at any scale between local to continental.

5.1.3.1 Ranking of indicator list

In addition to susceptibility, the scenario composition model is about ranking scenarios according to criteria combination patterns. The relevance of soil health indicators for the purpose of maintenance and enhancement of soil health varies with the type of land use. We have therefore undertaken a ranking of our indicators in terms of relevancy for particular types of land use. Since this exercise was meant to develop a methodology, this was kept to a minimum of three types of land use and one particular type of ecosystem, relevant for EU.

The majority of the European Union’s landscapes are shaped by a variety of valuable semi-natural habitats that find their origin and maintenance in farming. In fact, half of the land in the EU is farmed. Agriculture and nature, exercising a profound influence over each other, are selected as two main types of land use. For reasons of comparability, we chose to develop examples for grassland: dairy farming on grassland (agriculture) and meadow grassland (nature). For the urban environment, a parallel is sought in recreational park grassland.

A qualitative evaluation of indicators with respect to their relevance to grassland ecosystems under the above-mentioned types of land use is provided in Appendix 5G. Only indicators with known or assumed susceptibility for chemical stress have been evaluated; the ranking of importance is done by expert judgment in relative units on an increasing scale of 0 – 2.

5.1.4 Model for criteria setting

Toxicity data were searched for in the literature, to make up criteria (toxicity data sets) for indicators that are considered susceptible to chemical stress. The study has not been a very intense search, but was limited to recent scientific literature, to serve illustration purposes only. Databases and grey literature were not taken into account. Toxicity data were compiled for cadmium, as a well studied chemical stressor, and for compounds in the NoMiracle set of test substances: chlorpyrifos, diazinon, lindane and nickel. The availability of toxicity data for these chemicals is indicated in the last column of Appendices 5A to F, whilst data themselves are presented elsewhere (Faber et al. in prep). Examples of such toxicity data are presented in Appendix 5H. While the data are not exhaustive, a general overview and analysis may still offer interesting observations.

There are more studies available in the literature than included in our study. Especially for the pesticides diazinon, lindane and chlorpyrifos many references were not included because observed effects could not be related to concentrations of the active ingredient in the soil:

- Commercially available formulations of the pesticide were tested; the dosage was reported, but not actual soil concentrations of the active ingredient.
- Single dose applications; no dose-effect relationship was established.
- Studies involved repeated application in the field

From the overview it is clear that there are data gaps throughout the range of indicators: an absence of toxicity data for a particular indicator and chemical combination is frequently observed. Some of the chemicals are well studied (cadmium, chlorpyrifos), but still show a lack of (sufficient) data for a number of indicators. Data absence is the rule, rather than the exception. A full overview of available toxicity data may be addressed elsewhere (Faber et al., in prep.).

It is also clear that toxicity data are strongly clustered around particular indicators. Even for well-studied chemicals such as cadmium and chlorpyrifos it shows that if an indicator was tested at all, often several studies on the toxicity of a particular chemical were to be found. For example, cadmium and soil fertility: for epigeic earthworms, nine toxicity studies were readily retrieved, while for other types of earthworms or indeed other relevant soil fauna no data were found at all. Presence of data tends to be an "all or nothing" phenomenon.

Considering the different ecosystem services, soil fertility is not only the sub-problem with the highest number and problem diversity in terms of indicators, but also comes with the highest data availability. Nevertheless, even the high data density for this ecosystem service, as one of six sub-problems to the risk problem definition for land use, is far from a complete coverage. In the best case of cadmium data were retrieved for 40% of the susceptible indicators.

These general observations are thought to be of consequence, despite the inexhaustive nature of the data compilation. Appendices 5A-F may be used for indicative identification of data gaps. It may be concluded that the amount of recognised ignorance in further risk quantification would be substantial.

Appendices 5A-F may also be used for identification of relevant ecosystem aspects that should be investigated to come to a wider risk assessment with more generality. To some extent, the absence of toxicity data is due to a lack of ecotoxicological testing methods for the respective indicators. Here, Research Pillar 3 in the NoMiracle project may be inspired to develop new methods. To a larger extent though, research methods are available, but are waiting to be applied in ecotoxicological studies.

5.1.5 Scenario selection Model

This step of the System Model, as described in Chapter 2, is not included in this study. Further development of scenario descriptions for specified types of land use is needed for the approximation and quantification of sub-problems by criteria. As an example, a criterion data set is given here for soil fertility with respect to chlorpyrifos toxicity data available in the literature that were compiled for sensitive (obviously) indicators (Appendix 5H).

Specific criteria that are considered relevant for these types of land use may be further assessed for susceptibility to chemical stressors and risk scenarios may then be derived for soil health and suitability for use. If we know what to protect, we can establish thresholds for effects, derive PEC/NEC evaluations and produce risk maps, and identify vulnerable and threatened regions (cf. EU Soil Strategy tasking). Identified and validated indicators of soil ecosystem health may be used e.g. in the development of guidance to identify vulnerability of soils and land use under the future EU Soil Strategy.

At this point of the soil health scenario description, susceptible indicators may be used for the identification of high-risk scenarios with respect to soil contamination. The criteria sets on toxicity data can be used to assess the hazard of chemical stressors to identified soil health indicators. However, for the Scenario Selection Model to be successful in identifying high-risk areas in Europe with focus on chemical stressors, the scenario description also needs to include sub-problems describing causes of risk related to chemical soil contamination. This could be performed, as all other aspects of a risk scenario description, at different levels of generality.

5.1.6 Risk quantification model

This step of the System Model, as described in Chapter 2, is not included in this study. The presented scenarios may be used for the identification of sensitive and ecologically relevant parameters for toxicity testing (i.e. gaps in knowledge and data availability, cf. section 5.2) and evaluated by risk assessment elsewhere in the NoMiracle project (RP2, RP3, and RP4).

Based on the presented methodology for identifying the most sensitive and vulnerable soils with regard to chemical stress, the System Model Approach inclusive Scenario Selection and Risk quantification may be tested on a chemical by chemical basis. Assuming that all indicators susceptible to chemical stress have been identified (cf. Appendices A-F), the approach according to the four sub-models may be:

1. Extraction of highly relevant indicators for a land use specific Scenario Composition Model;

2. Definition of Criteria in terms of a description of toxicity measurements for indicators included in the Scenario Selection Model;

3. Definition of toxicity data sets included in the Criteria Model (e.g. lowest NOEC; range; median per indicator);

4. Scenario Selection Analysis to identify the most sensitive indicators per type of land use.

5. Establishment of critical threshold values for future soil health maintenance and/or enhancement.

Sub-problems defining exposure scenarios for specific areas and land uses in terms of source-emission-exposure mappings are needed together with a mapping of other stressors potentially influencing soil health as e.g. climatic stressors such as drought. In addition, further evaluation of indicators representing ecological requirements at higher specification levels need to be addressed for an evaluation of reliable most sensitive and representative vulnerability criteria (cf. section 5.2).

Future activities
In contrast to Chapter 4 we have not focussed on identifying the most hazardous chemicals, but aimed to develop a method to identify the most vulnerable soils as judged from the viewpoint of suitability for land use. We have not set out to actually pinpoint the most vulnerable types of land use, either; but the method we have developed may be used to do so.

In the 2nd phase of NoMiracle further elaboration is needed for the approximation and quantification of sub-problems by criteria in view of some specified types of land use. Specific criteria that are considered relevant for these types of land use may then be further assessed for susceptibility to chemical stressors; risk scenarios may then be derived for soil health and suitability for use. If we know what to protect, we can establish thresholds for effects, do PEC/NEC evaluations and produce risk maps, and identify vulnerable and threatened regions (cf. EU Soil Strategy tasking).

In addition, the present scenarios may be used for the identification of sensitive and ecologically relevant parameters for toxicity testing and risk assessment elsewhere in the NoMiracle project (RP2, RP3, and RP4). The scenarios may also be used e.g. in the development of guidance to identify vulnerability of soils and land use under the future EU Soil Strategy.

5.2 Ecological vulnerability in wildlife

This paragraph is an extended summary of methodology described in De Lange et al. (2006).

While toxicity data are lacking for most wildlife species, amply available autecological data may be used instead for ecological risk assessment by interpretation in terms of vulnerability to chemical stressors. Methodology was developed in NoMiracle WorkPackage 4.2 in order to assess wildlife vulnerability to some NoMiracle test compounds and other, well-known contaminants. Multi-criteria analysis and multi-variate analysis techniques were used on autecological species data to assess vulnerability for selected toxicants. Thus, vulnerable species and species traits can be recognised and used in scenario studies. As part of the work in WP4.2 an ecological vulnerability study is done (deliverable D426 (De Lange et al. 2006)), from which the data classification structure is reproduced below. Data have been collected for some 135 aquatic and terrestrial wildlife species, focussing on traits that determine external and internal exposure, toxicological sensitivity and population resilience.

The results include a ranking of species in relative order. Differentiation is made for the potential for bioaccumulation (Y/N), essential element (Y/N), with Cu, Zn, Cd and DDT as test compounds. Chlorpyrifos and ivermectin were also used as case study chemicals as a pesticide and

Multivariate analyses (PCA) are performed to evaluate the ecological traits in the database for their interdependency, and traits that contribute most to vulnerability.

5.2.1 Ecological vulnerability scenarios

Ecological characteristics were used to assess vulnerability in wildlife to chemical stressors. The selection of characteristics was done by experts in order to represent all important aspects from exposure to effect on population level. The characteristics are categorised into four main clusters, representing the pathway from exposure to effects at the population level (Table 5.1):

A. External exposure
B. Internal exposure
C. Effects at individual level
D. Effects on population level

Category A: External exposure	Category B: Internal exposure	Category C: Effects at individual level	Category D: Effects on population level
Habitat preference	Field Metabolic Rate	Intrinsic toxicological sensitivity	Age at first reproduction
Maximum life-span	Hibernation		Number of offspring in lifetime
Home-range	Season dependent presence		Survival juveniles until reproduction
Food preference	Storage organs		Dispersal capacity
Food needs	Excretion organs		Living-area patchy or dense
Hibernation	Detoxification mechanisms		Territorial behaviour
Season dependent presence			
Home range < distribution contaminant			

Table 5.1. Ecological characteristics by main category

External exposure: Characteristics in this category describe aspects in the biology of species that affect the likeliness and the extent of exposure to the contaminant.

Habitat preference determines whether an individual comes into contact with contaminants. A large home range, hibernation and seasonal presence reduce exposure to localised contaminants. Maximum life span is important for accumulating substances. Food preference describes the trophic level, and food needs the amount which is needed each day. These are important for chemicals with high potential for bioaccumulation. Some contaminants have a localised distribution such as insecticides applied at field scales, and veterinary pharmaceuticals distributed through cattle dung. This increases the hazard for species with a small home range, for species with a large home range the patchy distribution of the contaminant reduces the vulnerability.

Internal exposure: Characteristics in this category determine the internal concentration, activity and distribution of a substance within the body.
Field metabolic rate is important as it determines the rate at which internal processes such as excretion and detoxification are occurring. During hibernation and migration, the individual will use fat energy reserves. Substances that are stored in fat will become available in the blood, and the species is internally exposed.

Effects at individual level: This category describes the intrinsic toxicological sensitivity of the individual to the contaminant; this is comparable with traditional toxicological data.
In this category, effects of a contaminant on individual organisms are presented. Only one characteristic is used in this category: *toxicological sensitivity*. This means the sensitivity of a species when exposed by one or more contaminants.

Effects on population level: Characteristics in this category determine the effects on population level in relation to contaminants, the resistance to adverse effects, and potential for recovery after exposure (resilience).
These characteristics are aimed to give information on the field effects of contaminants on populations. Special focus is given on recovery from negative effects and the recovery rates. The higher the negative effects on a population (due to characteristics of the species involved) the more vulnerable a species is supposed to be. Characteristics describing reproduction, i.e. age at first reproduction, number of offspring in life, and survival to reproduction, are important in determining the population growth rate. Behavioural characteristics, dispersal capacity, patchy or dense distribution, or territorial behaviour, determine how easily individuals can move in from elsewhere to strengthen the local population.

5.2.2 Soil ecosystem contaminant scenarios

Different scenarios of contamination can be described, combining the exposure route and the contaminant type (Table 5.2.).

Contaminant type	Exposure site		
	Within soil	Aquatic	Soil surface
Regulated metal	copper, zinc	copper, zinc	
Non-regulated metal	Cadmium	cadmium	
Persistent organic pollutant	DDT	DDT	
Degradable organic pollutant	chlorpyrifos, ivermectin	(chlorpyrifos)	chlorpyrifos, ivermectin

Table 5.2. Position of selected contaminants in a matrix of contaminant type versus emission routes.

It is clear that soil ecosystems are complex – also regarding the description of exposure as already indicated in section 5.2.1. With respect to the System Model we have tried to include only very fundamental aspects related to exposure and effects in Chapter 4. Chapter 5, however, puts focus on the development of a more detailed description of soil ecosystem and wildlife vulnerability, the identification of soil health indicators of highest sensitivity, and relevance for the maintenance and enhancement of soil health (i.e. by reducing any undesired effects on the biological community and functioning of soils). For the purpose of scenario pre-selection for soil ecosystem risk assessment we will at best be able to include PEC's in terms of total soil concentration estimates, though not for all existing chemicals.

Different approaches may be adopted. In case of a successful identification of ecological vulnerability indicators at individual or population level, exposure may be described in terms of typical exposure mixture profiles related to typical contaminant sources. This approach addresses the validation of soil exposure markers and future use of ecological vulnerability indicators for the purpose of identifying areas of need for soil health enhancement action plans (e.g. remediation, contemporary changes in land use in purpose of soil ecosystem resilience processes to occur).

Alternatively, PEC's in terms of chemical by chemical PEC/PNEC evaluations may be used for setting up chemical-specific soil quality thresholds (if believed that the classical approach of protection is valid).

It may be a combination of the two types of approaches to re-evaluate the single chemical regulation and protection approach, and set up precautionary soil protection values for chemical contaminants. Mixture effects may be accounted for by classical PEC/PNEC assessment of single chemicals, and PNEC's at individual level be compared to population based ecological vulnerability indicator measurements.

In any case exposure may be included at local, national or EU level by use of TGD soil PEC values, or make use of georeferenced soil exposure modelled PEC's.

5.3 References

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